



A “V” shaped superconducting levitation module for lift and guidance of a magnetic transportation system

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ABSTRACT

A novel, YBCO based, magnetic transportation system (MagTranS) is presented and described. The feasibility of this system has been successfully tested and confirmed in a laboratory using a scaled demonstrator system. The MagTranS levitation system uses a stable, self-balancing “V” shaped superconducting module for both lift and guidance of vehicles. The work concept of the MagTranS levitation module is described and differences with regards to the maglev current systems are highlighted. The results of levitation tests performed using a measurement set-up are presented and discussed. Lastly, levitation module performance studies are also carried out using numerical finite element analysis.

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1. Introduction

The University of L'Aquila is currently developing a MagTranS research program aimed at developing and defining novel, YBCO bulk superconductor-based levitation technology. The levitation force of YBCO bulk superconductors makes them extremely useful in frictionless bearing transportation because of the inherent self-stability deriving from flux pinning phenomena. Chinese [1,2] and German [3,4] research groups have already proposed and tested demonstrator transport systems using onboard, high temperature superconductor (HTS) equipment that interacts with guideways employing permanent magnets (PM) assembled in opposite dipole symmetry, separated and sided by flux concentrators of steel. This configuration gives rise to a gradient field vertically to generate lift force while the lateral (guidance) force is only dependent on the trapped flux in the HTS bulk. Maglev vehicles are currently driven by a traditional alternate current (AC) linear motor.

We now introduce two new aspects with respect to this approach:

- (1) A “V” shaped self-balancing, magnetically-levitated module generating both stable lift and guidance (patent pending);
- (2) Propulsion provided by a direct current (DC) linear motor (patent pending).

In order to design and measure the main parts under static and dynamic conditions, tests were initially carried out using a ring model set-up [5–7]. The MagTranS scaled linear demonstrator sys-

tem was then manufactured and tested, and its feasibility and functionality were confirmed. This article concerns the lifting and guiding superconducting module of the MagTranS; the propulsion system is illustrated in another article which will be published shortly. Section 2 of this article illustrates and explains the basic aspects of the MagTranS and its technological characteristics. Many of the key results are in Section 3 where the lift and guidance system are presented. The concluding remarks are in Section 4.

2. MagTranS architecture

The MagTranS consists of two main contact-less parts:

- A. A track with three parallel iron-permanent magnet guideways (IPMG) fixed on the ground, the outer two of which are “V” shaped (VIPMG) and the central one is “U” shaped (UIPMG).
- B. A vehicle with “V” shaped HTS “runners” (VSR) onboard fixed to both sides of the body with DC power supplied copper coils mounted in the middle of vehicle.

The interaction between the components A and B above produces suspension and guidance, separate from propulsion. Stable lift and guidance of vehicle are generated by the interaction between VIPMG topside magnetic flux and the VSR under static and dynamic conditions. Propulsion of the vehicle is achieved through interaction between the magnetic flux of the UIPMG and the DC of the copper coils. Fig. 1 shows a photograph of the MagTranS demonstrator whose boogie (1) 0.72 m long and 0.81 m wide, levitates above the track (3.72 m long and 0.81 m wide) thanks to the magnetic interaction of the two outer VIPMGs (3) and the four simpli-

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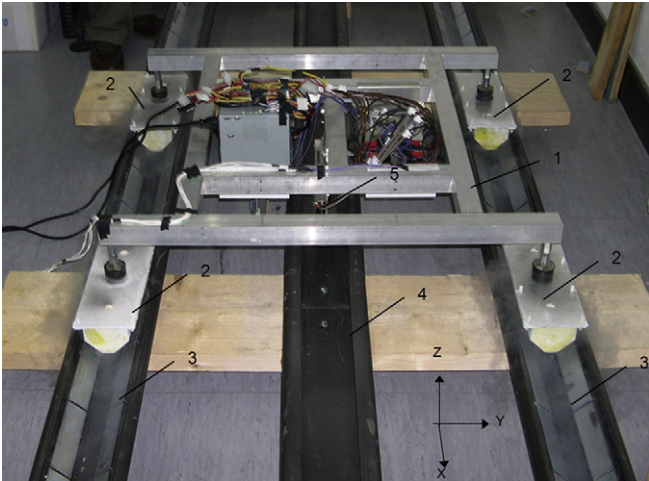


Fig. 1. View of MagTranS demonstrator.

fied VSR (2) each 0.28 m long; the boogie is driven by a vertical type linear motor using the central UIPMG (4) as the stator and the onboard DC coils (5) as the rotor.

As can be seen from Fig. 1, the MagTranS has an easily conceptualized architecture similar to a standard rail system: the four VSR are comparable to the wheels of vehicle, the two VIPMG and UIPMG replace the double-head and central contact rails, respectively. Although the linear drive does work as a braking system, vehicle motion is controlled on board by modulating and switching the power supply voltage. In practical terms, vehicle motion can be controlled by the vehicle itself or by an on board driver. The MagTranS can be used in an urban context, at low speeds and at high speed in extra-urban environments.

3. The MagTranS module for lift and guidance

The work concept of the MagTranS levitation module is based on the levitation force behavior of YBCO bulk superconductor. Pinning of the magnetic flux determines the levitation of the type II superconductor in a stable equilibrium state when the sample is levitating above or suspended below the PM. Let a bulk superconductor disk shaped be suspended below a PM at distance, where the magnetic flux density is B ; the magnet field is perpendicular to the disk plane and Z-axis is directed vertically and coincides with the disk axis. For this system, the weight of superconductor disk is balanced by the levitation force which can be calculated using the equation

$$F_z = J_c \cdot d \cdot (\partial B / \partial Z) \quad (1)$$

where J_c is critical current density, d is the perimeter of induced shielding current loops, and $\partial B / \partial Z$ is the gradient of magnet field.

Moreover, the levitation force is influenced by the shape and thickness of the bulk superconductor, field cooling process and operating temperature. In accordance with this theory, the MagTranS levitation module uses the VIPMG, the static magnetic field of which interacts with the VSR shaped in a complementary way to the first guideway. The VIPMG includes an iron beam within Ne-FeB permanent magnets arranged in the Y direction (direction of movement of the vehicle) according to two homopolar arrays facing each other, of opposite polarization along X. The VSR device consists of “V” assembled close arrays of melt textured YBCO monoliths immersed in liquid nitrogen kept at low temperature in a suitable cryogenic vessel with non-magnetic steel walls; this set-up is shown in Fig. 2.

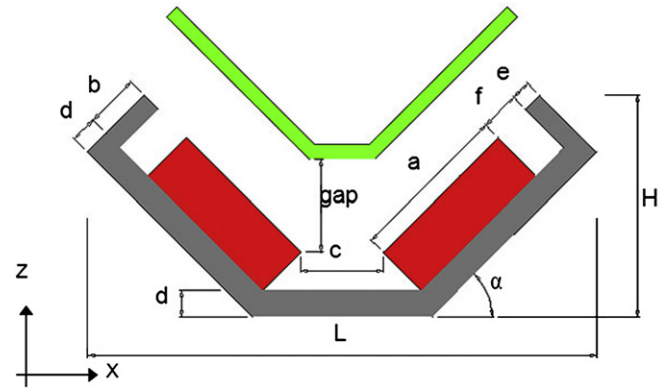


Fig. 2. Scheme of MagTranS levitation module.

To test the maglev performance of the MagTranS module, we developed the measurement scheme shown in Fig. 3. This set-up includes a simplified VSR mounted above a VIPMG section by means of a hydraulic jack, joined to a precision mechanical device, permitting variation in the operational heights (gap) between the two components. The levitation forces were tested on the VSR using a measurement system consisting of a bi-axial sensor.

The experimental VIPMG section, the main geometrical data of which are listed in line 1 of Table 1, is 380 mm long and uses a Ne-FeB PM with dimensions of $50 \times 40 \times 18$ mm. The experimental VSR of 190 mm uses melt textured YBCO samples (thickness of 11 mm) that are fixed in a cryogenic vessel (5 mm thickness multi-layers wall) filled with liquid nitrogen.

The transverse distribution of VIPMG magnetic flux density was measured first and the results are given in Fig. 4a and b show the vertical B_z and transverse B_x flux density components, respectively; Fig. 4c shows the vectorial B representation of flux density.

From Fig. 4 we can see that VIPMG generates a gradient field along the vertical Z and the transverse X directions: homogeneous field behavior along the Y direction is also achieved. It is also clear

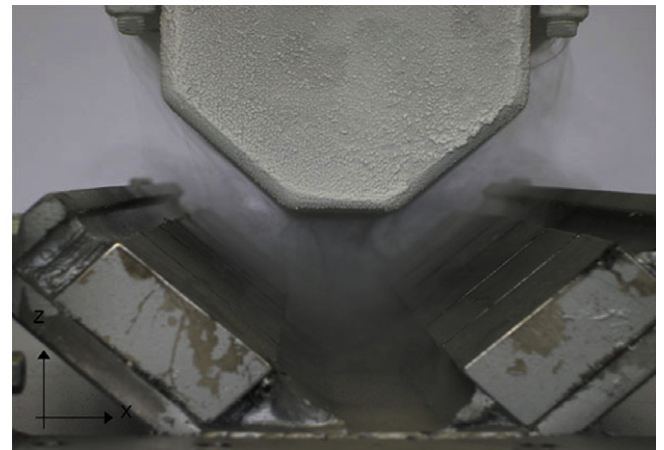


Fig. 3. View of experimental set-up.

Table 1
Data for four differently sized maglev modules

System size	α (deg)	a (mm)	b (mm)	c (mm)	d (mm)	e (mm)	f (mm)	L (mm)	H (mm)
1	45	40	18	31	8	6	10	147	60
2	45	87	29	62	15	10	30	296	121
3	45	123	41	62	20	15	30	385	167
4	45	150	50	62	25	20	30	451	202

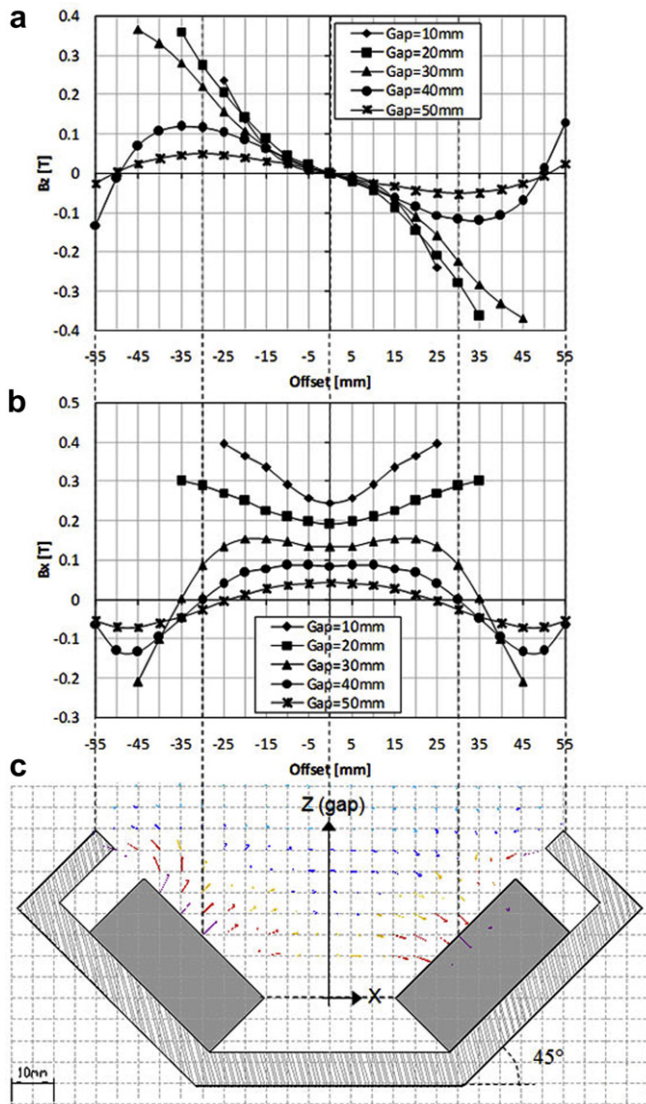


Fig. 4. Transverse distribution of magnetic field of VIPMG. (a) Flux density: vertical component (B_z). (b) Flux density: transversal component (B_x). (c) Flux density: vectorial representation (B).

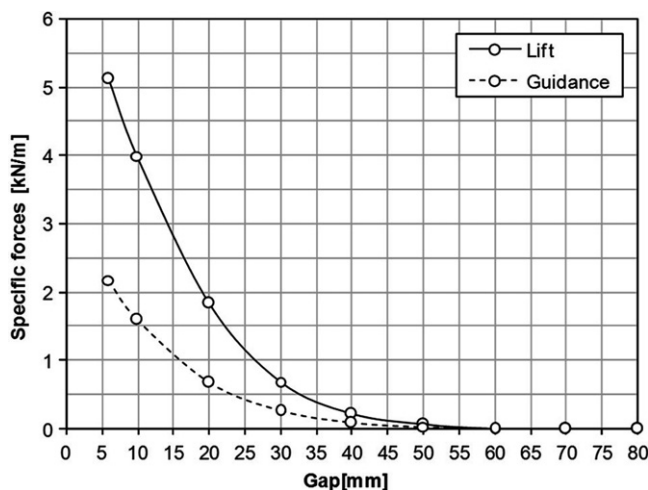


Fig. 5. Levitation performance vs. gap (experimental set-up).

how the B_z and B_x configurations depend on the prefixed inclination (α) of the “V” iron beam which, in this specific case, was 45°.

Secondly, levitation tests were performed by cooling the YBCO structure in zero magnetic field with liquid nitrogen. To compare levitation performance of different module sizes, we introduced a specific lift force F_z (N/m) and guidance force F_x (N/m) defined as the lift and guidance force generated by one linear meter of levitated module, respectively. Fig. 5 shows the results for levitation performance as a function of gap obtained by using the experimental set-up described above. From Fig. 5 we can see how significant levitation magnitudes at high gap values are achieved. The ratio between F_x and F_z is, on average, approximately 0.3; this high value is reached because the guidance force is obtained by using a lateral repulsive force.

The performance of the proposed maglev module was also evaluated using a finite element (FE) numerical model and agreement between numerical and experimental results was found. With reference to the symbols in Fig. 2, Table 1 lists the main data for four geometrically similar but differently sized MagTrans levitated modules. Size 1 corresponds to the module used in the experimental set-up shown in Fig. 3; the other three sizes are larger than the first and represent possible module configurations that could be used in real transport mass applications.

Fig. 6 shows specific lift and guidance forces vs. gaps for the 2nd, 3rd and 4th sizes calculated using numerical models. From Fig. 6 we can see that all three module sizes generate significant F_z and F_x values even at high gaps.

The results show that at 50 mm of gap two parallel 4th sized MagTrans levitation modules generate a specific lift force of about 34 kN/m (17 kN/m for each module) and a specific guidance force of 11.2 kN/m (5.6 kN/m for each module). To fully appreciate these results the obtained performances must be compared in the context of a functional maglev system (i.e. electromagnetic levitation system using normal electromagnets with a gap of 8 mm between the vehicle and guideway) where, the suspensions are designed to lift a specific mass of about 20 kN/m. The comparison highlights that MagTrans levitation forces are fully compatible with the requirements of high speed mass transportation applications. Moreover, it is evident that the MagTrans levitation module can be used also in different transportation applications (i.e. urban context at low speeds) by varying the design of its module size.

Moreover, it was fully verified and tested that this system configuration operates with a large air-gap and that no control

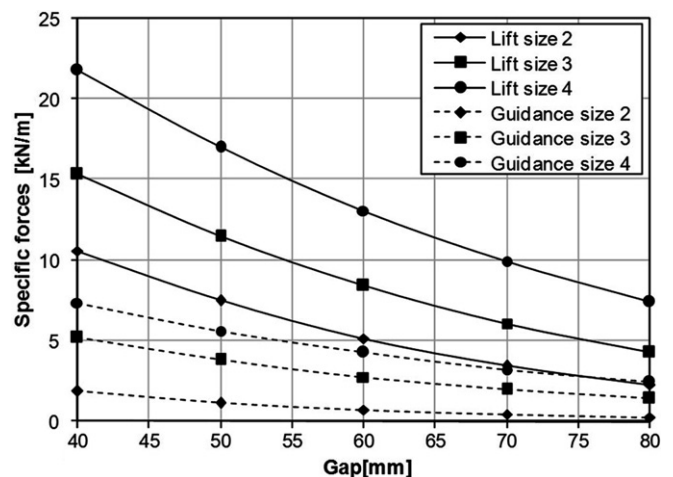


Fig. 6. Levitation performance vs. gap for three differently sized levitation modules (numerical analysis).

devices are required to keep the gap constant and no drag force is generated during the motion along Y [5–7]. In practical terms, the high magnitude of the guidance force allows significant speed even along curves while both the easy system architecture and commercially available materials keep infrastructure costs low and, indeed, comparable with traditional wheel-based system costs.

Fig. 7 shows a cross section of the flux line configuration of VIPMG obtained using the numerical model. As can be seen from this figure, the soft magnetic steel beam works as a flux collector to enhance the magnetic field and as a mechanical structure for transferring and distributing the static and dynamic stress (due to vehicle motion) to the ground.

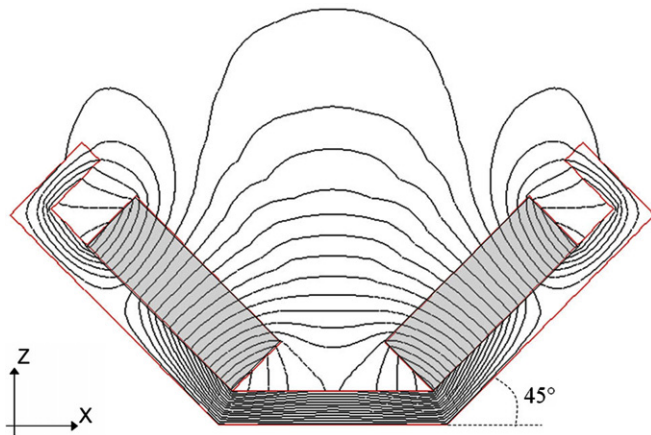


Fig. 7. Flux line cross section of VIPMG.

Fig. 8 also shows the numerical results of maglev module reactions when the VSR is differently stressed. Fig. 8a shows the flux line configuration and system reaction when the VSR is perfectly lifted and centered on VIPMG; this configuration corresponds to a minimum energy level of the system. Fig. 8b–d shows the system reactions when the VSR is off-set by the central configuration by means of external actions, such as a vertical stress S_z , a transverse stress S_x , and a rolling moment M_y , respectively. In all these cases, the maglev module instantaneously produces re-balancing reactions in opposition to external actions in order to center the VSR on the VIPMG again and reach the minimum energy level of the system.

Therefore the advantages of the MagTranS levitation module are:

- The self-stabilizing magnetic lift and guidance module without any control system use.
- The high ratio between guidance and lift forces.
- High working gap that, as a result, does not require high precision track manufacturing.
- The absence of drag forces (magnetic resistance) during motion.
- The confinement of the magnetic field in the guideway structure without any environmental interference.
- Adaptability to dense urban areas and extra-urban (high speed) environments.
- System lifespan, low maintenance and costs comparable with those for traditional systems.

We believe that for all of the above mentioned reasons, MagTranS technology can resolve many of the problems that have hindered a more widespread use of maglev mass transportation systems.

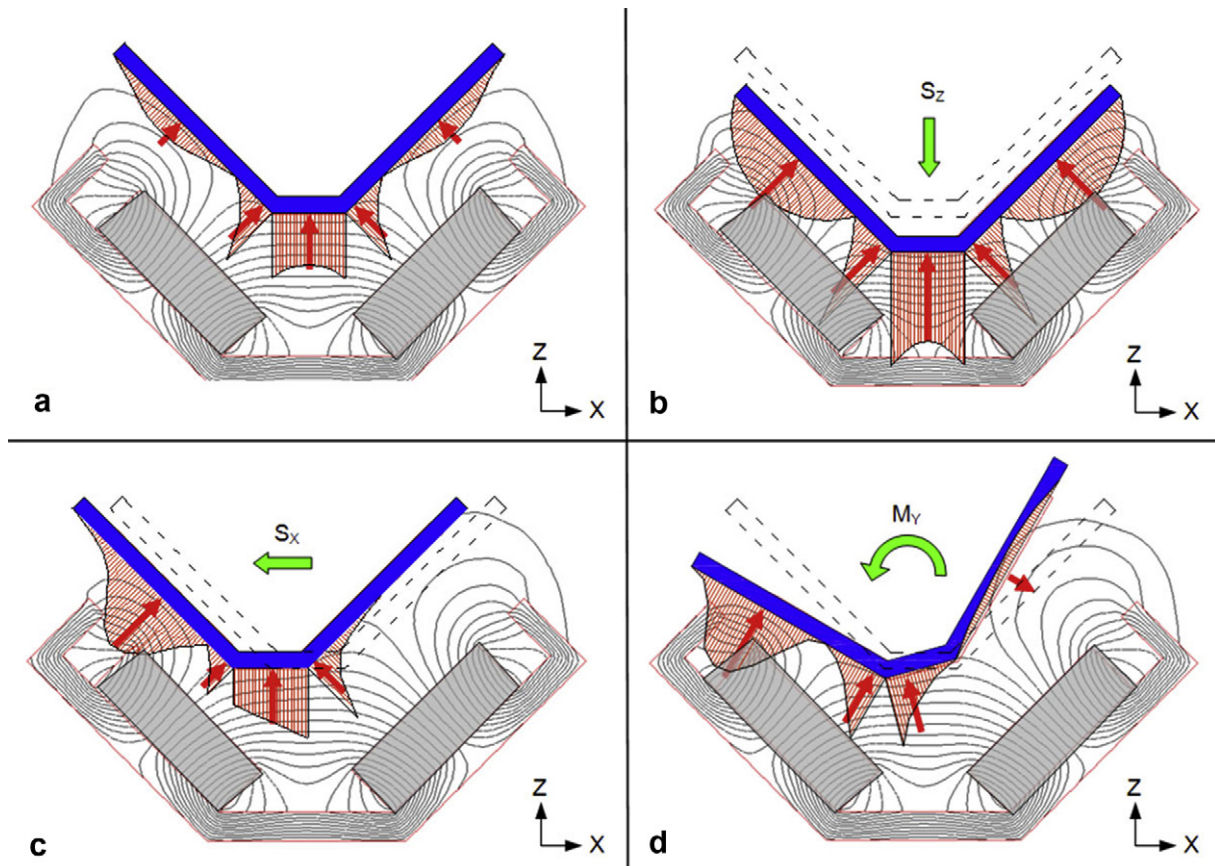


Fig. 8. Magnetic reactions of maglev module under differing stress conditions.

4. Conclusion

To summarize, a novel YBCO based and DC propelled MagTranS has been presented and its technical feasibility confirmed using a scaled system demonstrator. The MagTranS “V” shaped levitated module performance was tested using a measurement set-up and was also analyzed using FE models. The results show that the MagTranS module generates both stable lift and guidance forces without magnetic resistance (drag forces). No control systems are required and no environmental magnetic interference is produced. The proposed maglev module is fully compatible with requirements for mass transport applications because of its high levitation performance, inherent self-stability, self-balancing, high gap functioning (about 20–40 mm) and high ratio (about 1/3) between

guidance and lift forces. The future implementation of the demonstrator is based on the construction of a full working prototype for passenger transport.

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